BITUMEN EMULSION COLD-MIXTURES - A FEASIBLE PAVEMENT CONSTRUCTION MATERIAL IN TANZANIA

by

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ABSTRACT

Most of the flexible pavements in Tanzania are constructed using Bituminous Hot –Mixes, while a few of them consist of Cold-Mixes. The conventional Bituminous Hot-Mixes are generally known to be stronger and more durable than other types of mixes. However, they are associated with some economic disadvantages, environmental hazards and safety problems.

The extent to which Bituminous Cold-Mixes (BEMIX) can be used in pavement construction in Tanzania, with the objective of overcoming some of the disadvantages that are associated with the use of Hot-mixes, has been investigated.

The current research consisted of sampling some of the commonly used Road aggregates and some locally blended Bitumen Emulsions; making trial mixes and evaluating their strength using the Marshall Stability criteria. In the course of this study, it has been found that BEMIX can be successfully employed as a paving mixture for the construction of Road bases as well as surfacing courses. Test results have shown that BEMIX can attain soaked Marshall values of between 5000 and 10,000 Newtons, after curing in oven at 40^{o}C for 24 hours, followed by soaking in water for another 24 hours.

One of the Bitumen Emulsion Cold-mixes that was designed during this research was successfully used as a Road base course material, during construction of a pilot project done in Morogoro Municipality, in August 1998. This project was jointly funded by Swiss Government and Government of Tanzania, under Morogoro Road Support Project (MRSP), and it was meant for training of Engineers and Contractors in Road construction using Bitumen Emulsion Cold-Mixtures.

1. INTRODUCTION

A commonly used pavement structure in Tanzania is the flexible pavement type, whereby a Bituminous mix or surface treatment is placed over a base course made of granular materials. Other flexible pavement types being used consist of base courses made of bituminous mixes or penetration macadam [Ministry of Works, 1999]. The Bituminous mixes used in the construction of the surfacing and base course layers are hot-mixed, hot laid and compacted and are normally referred to as “Hot-Mixes”, or Bituminous concrete, or Asphalt Concrete.

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The processes involved in producing the hot mixes consume enormous energy such as electricity, fuel oils and or firewood. This is one of the causes of high construction costs on one hand, and on the other hand the heating processes cause some environmental pollution in form of dust and poisonous fumes, and sometimes fire accidents occur to workmen and the surroundings.

One possible approach to overcome the disadvantages associated with Bituminous hot-mixes is to use Bitumen Emulsion cold-mixes (BEMIX). Bitumen Emulsion-cold Mixes can be produced and constructed without application of heat, and therefore are economical. Environmental pollution in form of poisonous fumes and dust, and risk of fire accidents to workmen and surrounding are eliminated, as no heating process is involved.

The Ministry of Works has recently started considering BEMIX as an alternative pavement construction and maintenance strategy. In August 1998, a Pilot project was launched in Morogoro Municipality as a training project in Bitumen Emulsion Paving Mixtures. The design of Bitumen Emulsion cold-Mix was conducted at Project Laboratory, but the mixture did not attain the expected Marshall Stability values, which were specified for the project.

Following failure of the mix design at the pilot project, further studies were initiated, which formed part of the research reported herein. Additional samples from the pilot project were taken for further analysis and redesigning of the mixture.

2 BITUMEN EMULSION COLD- PAVING MIXTURES

The main ingredients of Bitumen Emulsion Cold paving mixtures are Bitumen emulsion binder and mineral aggregates, which are mixed without application of heat, either as plant-mix or as mixed-in-place.

In the current study, three types of rock aggregates, and two types of locally blended bitumen emulsions were used to make four mix designs as follows:

i) BEMIX A

This consisted of Coral limestone aggregates from Kunduchi quarry in Dar Es Salaam, and cationic bitumen emulsion grade K-3A, that had 4% of diesel oil flux. This mixture was proposed for use in base course construction.

ii) BEMIX B

This consisted of granite mineral aggregates from Lugoba quarry in Bagamoyo, blended with sand and cement filler, and cationic bitumen emulsion grade K-3A, which also had 4% of diesel oil flux. This mixture had been proposed for use in surfacing course.

iii) BEMIX C

This consisted of Schist rock aggregates mixed with quartz, quarried at Melela in Morogoro, and cationic bitumen emulsion with 4% diesel oil flux. This is the base course mixture which had been designed for the training Project in Morogoro, where it had failed to meet the Marshall mixture design criteria [ITECO, 1999]

iv) BEMIX D

This was the new base course mixture requested for the Training project in Morogoro following the failure of the first one. It consisted of Melela aggregates and cationic bitumen emulsion grade K-3A consisting of 2% kerosene oil flux [ITECO, 1999].

All aggregates and bitumen emulsions intended for use in the proposed bitumen emulsion cold-mixtures (BEMIX), were subjected to the relevant quality tests for the purpose of checking the compliance of the same with the specifications laid down for such materials. Bitumen emulsions were subjected to Water content test and Penetration test on residue; while tests on mineral aggregates included Gradation analysis, Los Angeles Abrasion test, Proctor compaction, Plasticity Index on fine materials and Specific gravity [ASTM, 1988; and AASHTO, 1986].

3 MIX DESIGN OF BITUMEN EMULSION COLD MIXTURES

After ascertaining the quality of the component materials, the paving mixtures were designed using Marshall method for Emulsified Bitumen-Aggregate cold Mixture. This method is based on research conducted at the University of Illinois using modified Marshall method of mix design and moisture durability test [Asphalt Institute, 1987]. The design procedure consist of the following major steps:

(i) Approximation of Bitumen Emulsion content for trial mixes.
(ii) Determination of minimum mixing water (Coating Test).
(iii) Determination of optimum water content at compaction.
(iv) Variation of residual Bitumen content.
(v) Modified Marshall stability and flow tests on dry specimens.
(vi) Modified Marshall stability and flow tests on soaked specimens.
(vii) Density and Voids analysis.
(viii) Presentation of Test results.
(ix) Determination of Optimum Bitumen content

4 MIX DESIGN RESULTS

For each mix design, the following characteristics were determined and plotted against the residual bitumen content:

a) Dry and Soaked Stability
b) Dry Bulk Density
c) Percent Stability Loss.
d) Percent Total voids
e) Percent moisture absorbed.

From the graphical plots, the optimum or design bitumen content had been determined, and the test property values corresponding to the optimum or design bitumen content were read from the respective plots.

Table 1 below presents the summary of the mix design results for the four trial mixes.

TABLE 1: Summary of Bitumen Emulsion Cold-Mix Design Results

	BEMIX A	BEMIX B	BEMIX C	BEMIX D	DESIGN CRITERIA
Optimum (Design) Bitumen Content (%)	5.0	3.8	4.0	4.5	-
Soaked Stability (N)	5,000	10,000	5,070	6670	Min. 4500**
Percentage Stability Loss	34	9.0	2.5	+16	Max. 50*
Flow (mm)	3.0	2.0	3.5	3.0	2 – 4**
Moisture absorbed (%)	3.0	3.2	2.8	24	-
Max. total Voids (%)	17.4	14.0	13.0	11.8	*** values

** Ministry of Works Pavement and Design Manual, 1999. *Asphalt Institute Manual, MS-19
*** Asphalt Institute Manual, MS-2

4.1 BEMIX A

Results of mix design for BEMIX A are displayed in Table 2A below, and graphical plots of the same are shown in Figure A.

TABLE 2A: Results Of BEMIX Design A

SUMMARY SHEET FOR BITUMEN EMULSION MIXTURE DATA			
MARSHALL METHOD FOR BEMIX DESIGN			
EMULSION		AGGREGATE	
Type and Grade	K-3A (4% GO)	Source Ident.	Kunduchi Quarry
Bitumen in Emulsion %	60	Type:	Limestone Aggregate……70% Crusher dust……………..20% Sand……………………...10%
MIXING AND COMPACTION		TESTING	
Total Mix water %	4.75	Dry specimen Testing date	11-6-99
Optimum w.c. at compaction %	2.4	Soaked specimen Testing date	15-6-99

AVERAGED SPECIMEN DATA

Residual Bitumen in mixture %	Bulk Specific Gravity	Dry Bulk Density g/cc.	Adjusted Marshall Stability value (kN)		Stability Loss (%)	Flow (mm)	Moisture content (%)		Moisture absorbed (%)	Maximum total voids (%)
			Dry	Soaked			Dry	Soaked		
3.5	2.128	2.080	9.47	2.65	-72	2.0	2.4	8.3	5.9	19.7
4.5	2.138	2.084	8.26	3.70	-55	2.5	2.5	6.4	3.9	18.2
5.5	2.148	2.095	6.80	5.08	-25	3.4	2.7	5.1	2.4	16.6
6.5	2.138	2.089	5.70	5.69	0	4.0	2.5	3.8	1.3	15.9
7.5	2.123	2.069	4.27	4.22	1	5.1	2.8	3.0	0.2	15.6

From the graphical plots given in Figure A, the test results exhibited the following trends:

- Dry Marshall Stability decreases with increasing bitumen content, while Soaked Stability shows a peak at one bitumen content.
- Percentage Loss of Stability decreases with increasing bitumen content, up to a point from which it maintains a value of zero.
- Dry bulk density increases with bitumen content up to a maximum, and thereafter it decreases with further increase in bitumen content.
- Percent moisture absorbed during soaking test decreases with bitumen content
- Percent total voids decreases as bitumen content increases.

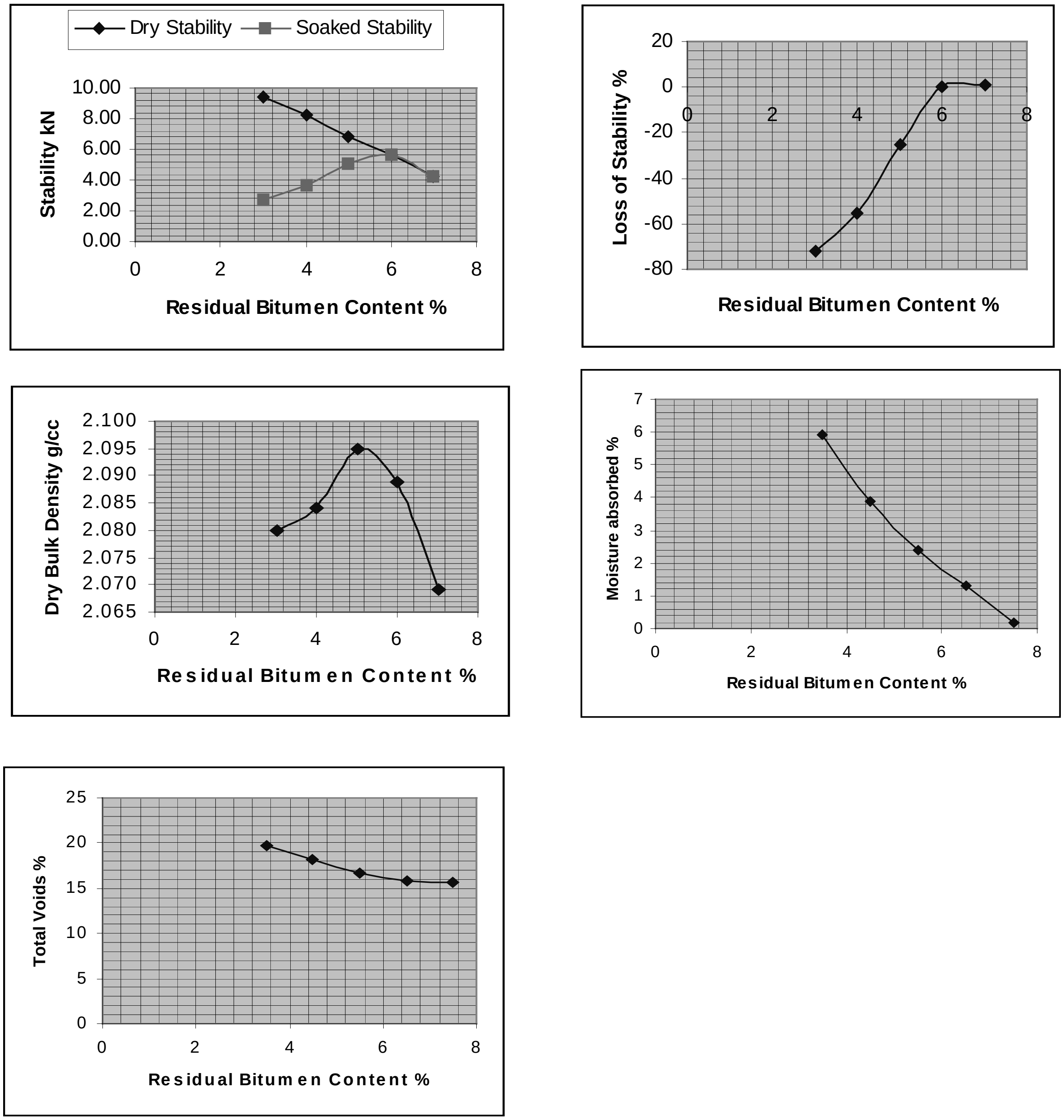


Figure A: **Plots of BEMIX Design A**

From the graphical plots, bitumen content corresponding to the turning points of the soaked Marshall value and dry bulk density curves, was selected as the optimum bitumen content, and this was found to be 5.0%. At this selected optimum Bitumen content, the mixture had the test property values given in column 2 of Table 1.

According to the Mix Design criteria given in column 6 of Table 1, this paving mixture can be used successfully for construction of Base course. However this cold mixture cannot be adequate for construction of Surface course for pavements carrying heavy vehicles due to the high Los Angeles Abrasion value of the Limestone aggregates used in the mixture. From the Aggregate test results, these aggregates have a value of 36%, while specifications require a maximum of 30% for Surface course aggregates (Road Note 31).

4.2 BEMIX B

Results of mix design for BEMIX B are displayed in Table 2B below, and the corresponding graphical plots are shown in Figure B

TABLE 2B: Results of BEMIX Design B

SUMMARY SHEET FOR BITUMEN EMULSION MIXTURE DATA					
MARSHALL METHOD FOR BEMIX DESIGN					
EMULSION			AGGREGATE		
Type and Grade	K-3A (4% GO)		Source Id.	Lugoba - KONOIKE Quarry	
Bitumen in Emulsion %	60		Type	20 mm…20% Sand……..12% C/dust…27% 5 mm…….12% 13mm....25% Filler……...4%	
MIXING AND COMPACTION			TESTING		
Total Mix water	%	6.3	Dry specimen Testing date		26-7-99
Optimum w.c. at compaction	%	2.0	Soaked specimen Testing date		27-7-99

AVERAGED SPECIMEN DATA

Residual Bitumen in mixture %	Bulk Specific Gravity	Dry Bulk Density g/cc.	Adjusted Marshall Stability value (kN)		Stability Loss (%)	Flow (mm)	Moisture content (%)		Moisture absorbed (%)	Maximum total voids (%)
			Dry	Soaked			Dry	Soaked		
3.0	2.336	2.291	12.51	11.45	-15	0.9	0.9	4.8	3.9	16.5
4.0	2.365	2.334	10.62	9.80	-8	1.8	1.1	4.8	3.7	13.6
5.0	2.328	2.326	8.40	8.20	0	2.2	1.3	4.0	2.7	12.5
6.0	2.340	2.297	6.40	6.80	+8	2.3	1.2	3.5	2.3	12.4
7.0	2.295	2.284	4.40	5.80	+16	3.1	1.0	2.6	1.6	11.6

From the graphical plots shown in Figure B, the test results displayed the following trends:

- Both dry and soaked Marshall Stability decrease with increasing bitumen content, without showing any peak point.
- Percent Loss of Stability decreases with bitumen content.
- Dry bulk density increases with bitumen content up to a point where it reaches a peak, and then starts decreasing.
- Percent moisture absorbed and Total voids decrease as bitumen content increases.

According to the test results given in Table 2B and Figure B, the mixture did not show any significant drop in Marshall Stability value, following soaking in water for 24 hours. The Soaked Stability graph had literally merged with that of Dry Stability, contrary to that obtained in BEMIX A. This can be explained by the fact that, the Aggregates used in this mixture contained fines which were non-plastic. The non-plastic fines do not absorb moisture and undergo swelling, which would result in decrease in density and hence the Stability.

MARSHALL METHOD FOR EMULSIFIED ASPHALT MIX DESIGN

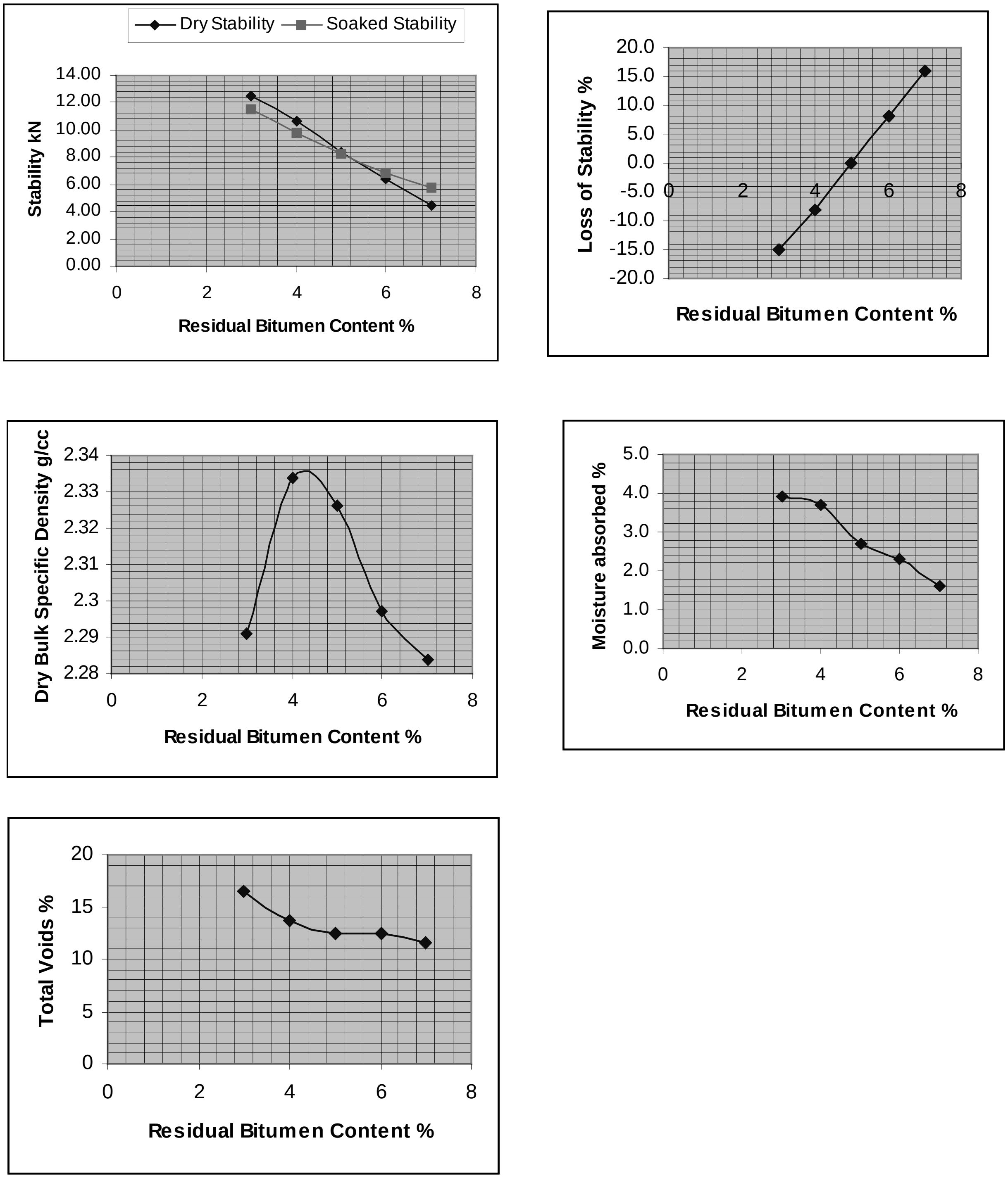


Figure B: **Plots of BEMIX Design B**

Since the Soaked Marshall Stability graph did not make a turning point, the selection of the optimum Bitumen content was based on the Dry Density curve, and the requirement for total voids in the mix. Since the maximum size of aggregates used was 20mm, the design criteria [Asphalt Institute, 1984] requires a minimum total voids of 14%.

The design bitumen content thus selected was 3.8%, and the mixture had the test property values as given in column 3 of Table 1

Of all the mixes designed in this study, this one attained the highest Marshall Stability values, both Dry and Soaked. This mixture also had cured faster than the others. The cement filler added to the aggregates used in this mixture, explains the reason for early curing and subsequent early strength development [Asphalt Institute, 1887]. This mixture not only fulfils the Stability requirement for BEMIX given in Table 1, but also meets the requirements stipulated in Asphalt Institutes Manual MS-2 for Asphalt concrete (Hot mix), for Heavy Traffic pavement Surface and Base courses. In the Marshall Design Criteria for Hot Asphalt Concrete, the minimum Stability value for Heavy Traffic pavement Surface or Base is 6672 Newtons, whereas this mixture attained an average soaked stability value of 10,000 Newtons.

4.3 BEMIX C

Results of mix design for BEMIX B are displayed in Table 2C below, and plots of same, are shown in Figure C.

TABLE 2C: RESULTS OF BEMIX DESIGN C

SUMMARY SHEET FOR BITUMEN EMULSION MIXTURE DATA			
MARSHALL METHOD FOR BEMIX DESIGN			
EMULSION		AGGREGATE	
Type and Grade	K-3A (4% GO)	Source Ident.	Melela NPP Quarry
Bitumen in Emulsion %	60%	Type:	25 mm…..25% 5 mm…..10% 12.5 mm...20% 2 mm…..45%
MIXING AND COMPACTION		TESTING	
Total Mix water %	5.24	Dry specimen Testing date	19-7-99
Optimum w.c. at compaction %	2.0	Soaked specimen Testing date	20-7-99

AVERAGE SPECIMEN DATA

Residual Bitumen in mixture %	Bulk Specific Gravity	Dry Bulk Density g/cc.	Adjusted Marshall Stability value (kN)		Stability Loss (%)	Flow (mm)	Moisture content (%)		Moisture absorbed (%)	Maximum total voids (%)
			Dry	Soaked			Dry	Soaked		
3.0	2.325	2.305	5.50	5.57	5.0	2.6	0.5	5.1	4.6	14.0
4.0	2.350	2.320	5.44	5.07	2.5	2.9	0.9	4.4	3.5	13.2
5.0	2.331	2.319	4.24	4.03	0.0	3.0	1.2	3.6	2.4	12.0
6.0	2.330	2.308	3.76	3.46	-4.5	4.6	1.3	2.9	1.6	9.9
7.0	2.334	2.307	3.27	3.32	-9.0	5.9	1.3	2.3	1.0	9.4

From Figure C, the test results exhibited the same trends as that of BEMIX B, except for the Percentage Loss of Stability, which increases with bitumen content. The design bitumen content was determined following the same procedure used for BEMIX B above. The maximum aggregate size used is 25mm, which requires a minimum total voids of 13%

This mixture attained a soaked Marshall Stability of 5.07 kN at an the design bitumen content of 4.0%, and the test property values corresponding to this design bitumen content are as shown in column 4 of Table 1. While the mixture attained this value of stability during this study, the same mix achieved less than half of this value at the pilot project laboratory in Morogoro.

The improvement in the Marshall Stability value follows some modifications made in the proportions of the aggregate fractions, and determination of appropriate water content at compaction.
As with BEMIX B, this material which also contained non-plastic fines, did not show substantial loss in Stability after soaking in water. From the results obtained in this study, this mixture satisfies well the design criteria for Base course material as given in Table1.

MARSHALL METHOD FOR EMULSIFIED ASPHALT MIX DESIGN

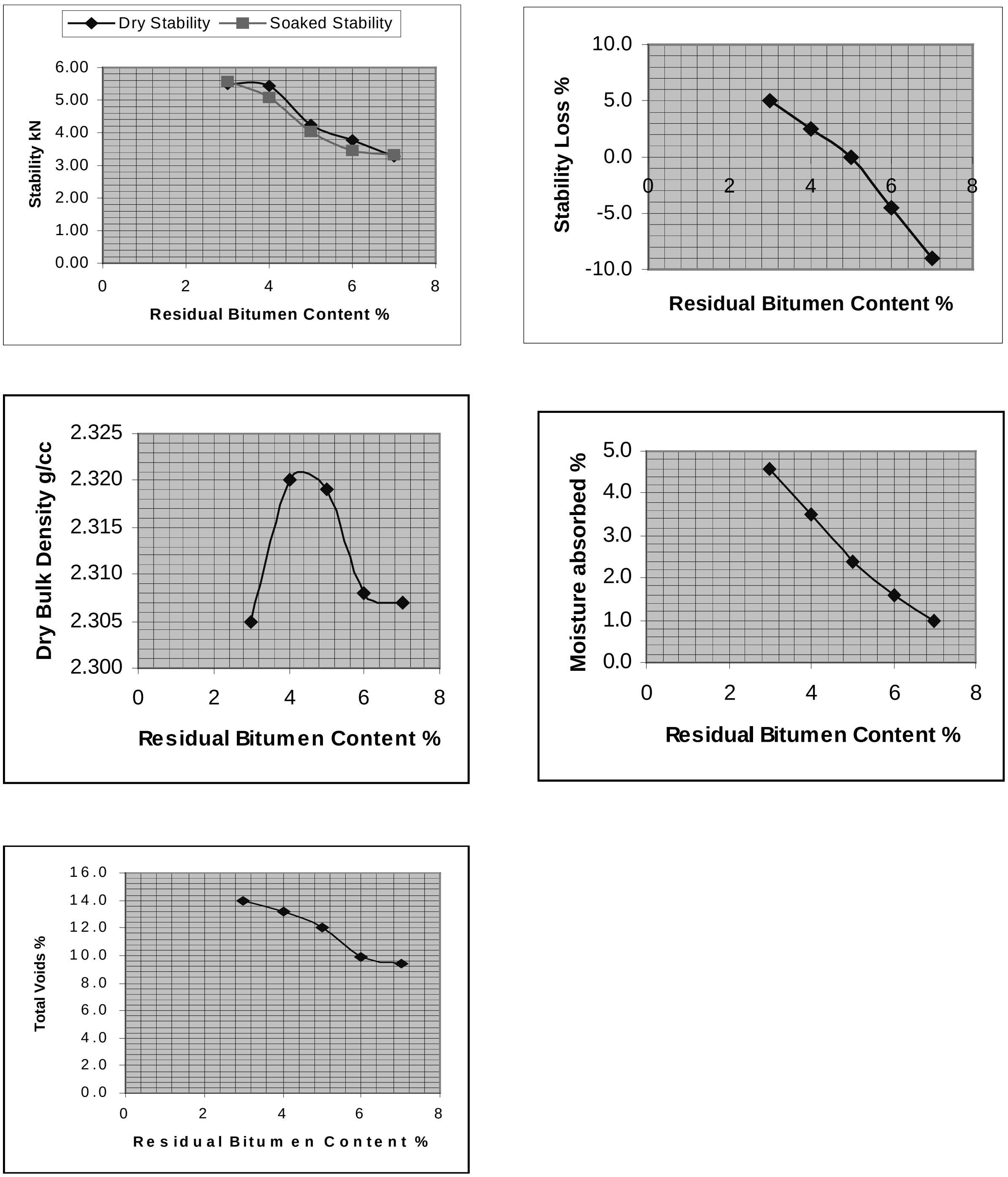


Figure C: Plots of BEMIX Design C

4.4 BEMIX D

This mixture consisted of the same type of mineral aggregates as that used in BEMIX C, but used Bitumen Emulsion K-3A, which had 2% Kerosene flux. Results of mix design for BEMIX B are displayed in Table 2D, and are plotted in Figure D

The trends and relationship of test data were similar to those of BEMIX C. For the same reasons stated for BEMIX B and C above, this mixture didn’t loose Stability under the influence of water following 4 days of soaking. The soaking duration of this mixture had been increased from 24 hours to 4 days so as to study how it would differ from BEMIX C which had the same kind of aggregates and had been soaked for 24 hours. The test results showed that all Soaked Marshall stability values had increased above the Dry values by an average of 12%. The increase in Soaked Stability values was only due to increase in the curing duration, since soaking of the mixture with non-plastic fines has no effect as already stated previously.

As for BEMIX C, the determination of design Bitumen content was based on the Dry density curve and total voids requirements in the mixture, and it was found to be 4.5%. The test property values of the mixture corresponding to the design bitumen content are given in column 5 of Table 1.

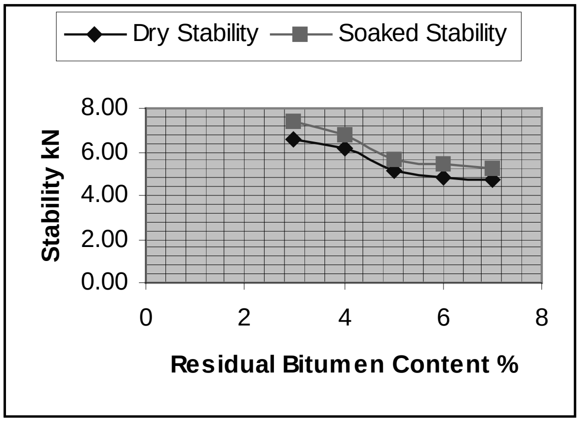
This mixture also meets the Design criteria given in Table.1, as Pavement Base course material.

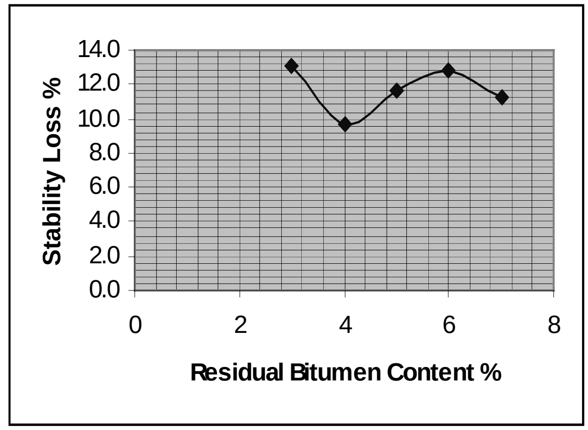
TABLE 2D: Results of BEMIX Design D

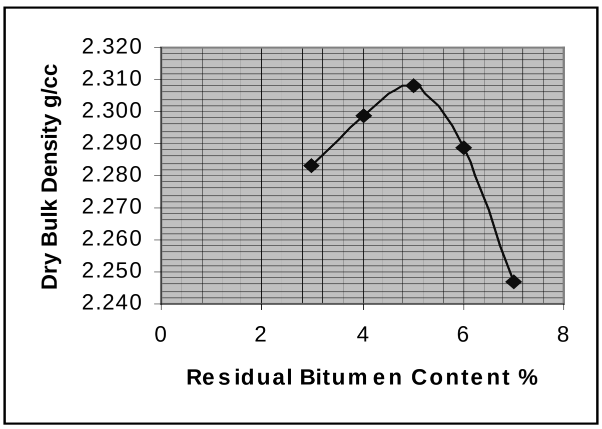
SUMMARY SHEET FOR BITUMEN EMULSION MIXTURE DATA			
MARSHALL METHOD FOR BEMIX DESIGN			
EMULSION		AGGREGATE	
Type and Grade	K-3A (2% IK)	Source Ident.	Melela NPP Quarry
Bitumen in Emulsion %	60	Type:	25 mm 25% 5.0 mm 10% 12.5 mm 20% 2.0 mm 45%
MIXING AND COMPACTION		TESTING	
Total Mix water %	5.24	Dry specimen Testing date	23-7-99
Optimum w.c. at compaction %	2.2	Soaked specimen Testing date	26-7-99

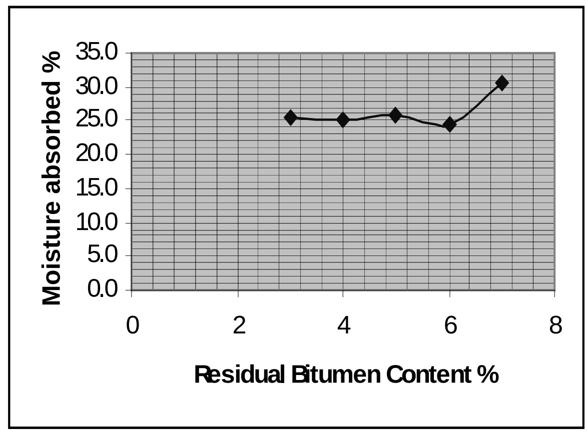
AVERAGE SPECIMEN DATA

Residual Bitumen in mixture %	Bulk Specific Gravity	Dry Bulk Density g/cc.	Adjusted Marshall Stability value (kN)		Stability Loss (%)	Flow (mm)	Moisture content (%)		Moisture absorbed (%)	Maximum total voids (%)
			Dry	Soaked			Dry	Soaked		
3.0	2.290	2.283	6.55	7.41	13	2.5	2.2	23.3	25.5	14.8
4.0	2.313	2.289	6.20	6.80	10	3.1	0.9	24.1	25.0	13.9
5.0	2.342	2.308	5.10	5.69	12	3.8	1.1	24.7	25.8	12.8
6.0	2.323	2.299	4.81	5.43	13	5.5	1.3	23.1	24.4	10.6
7.0	2.275	2.247	4.73	5.26	11	6.4	1.2	29.4	30.6	11.7









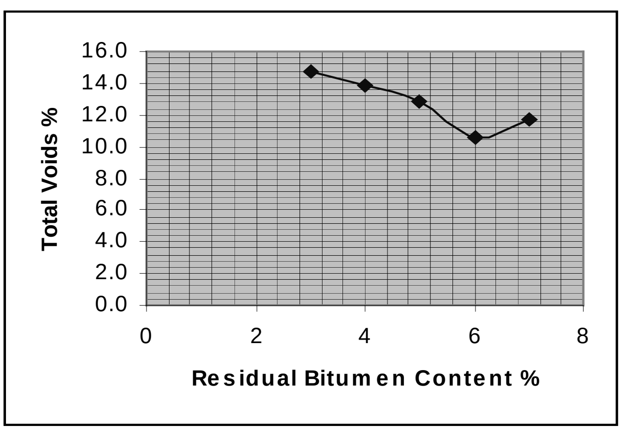


Figure D: Plots of BEMIX Design D

6 CONCLUSIONS AND RECOMMENDATIONS

- The Results of this study indicate that Bitumen Emulsion Cold-Mixtures (BEMIX), are suitable in Pavement Construction or Rehabilitation in Tanzania. The mixtures can be used in Base courses and as trial mixes in Surface layers of Pavements designed for the current level and type of Traffic, provided they are properly Designed and Constructed.

- In the Design stage, care should be exercised in selecting materials, which meet the Project specifications. The mineral aggregates should meet Gradation, Durability and Strength requirements for the type of construction and level of Traffic expected to use the pavement. In projects where early mixture strength development is critical, cement filler that accelerates curing of the mixture can be included in the aggregates.

- Bitumen Emulsion used in the mixtures should be of the right type and grade, and should be in a consistency that permits easy coating of the aggregates and good workability of the mixture. Aggregates with non-plastic fines such as rock dust are highly recommended for Base and Surface course Bitumen Emulsion cold-mixes if they can be economically procured. Cold-mixes containing of non-plastic fines don't loose Stability under the influence of water, a phenomena which is an advantage to the performance of the pavement.

- As Tanzania is still at infant stage, as far as use of BEMIX in Road works is concerned, the following recommendations are made in order to make full use of the advantages of the cold-paving mixtures.

  (i) An extensive research on the performance of different aggregates from different parts of the country, with different types of Emulsions, should be conducted. This will enable the country to have a central data base of the available aggregates and their performances.

  (ii) Research should be done on the Rate of Strength development of Bitumen Emulsion cold mixes used in Tanzania, in order to determine the time taken for particular mixes to attain the final strength, and the magnitude of the final strength that can be attained.

  (iii) Further Research on the Economy of Bitumen Emulsion mixtures should be done in the future, when a few projects involving BEMIX have been undertaken in Tanzania, so as to compare with the conventional hot asphalt concrete constructions.

  (iv) Pavement evaluation studies should be conducted regularly on the pilot project, in order to establish the performance of the pavement materials.

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